

## GENERAL IDEAS ABOUT BEAM DESIGN FOR NAL

W. T. Toner  
Stanford Linear Accelerator Center

July 1, 1968

### Summary

Useful limits to the definition of beam phase space are considered from a general point of view. Some points of interest are:

1. A lower useful limit to the definition of the transverse momentum is set by coulomb scattering in the experimental target. Six inches of liquid hydrogen is enough to produce an uncertainty of  $\pm 3$  MeV/c per particle.
2. The  $\int B dl$  along the pole-tips of quadrupoles at the front ends of beams is determined by the maximum spread in transverse momentum which it is desired to capture. High-flux beams will need  $\int B dl$  approaching 100 kG-meters. At the experimenter's end of the beam there will be a need for quadrupoles with  $\int B dl$  of only 10 kG-meters at the pole-tips.
3. The strongest constraints on beam length, bending angles, etc. will be the usual ones: avoidance of shielding and other experiments. This leads to bend angles much greater than needed for momentum resolution.

What are the "desirable" values for the phase-volume definition in transverse phase space,  $x, \dot{x}, y, \dot{y}$ ?

### Beam Spot Size

A few cms diameter is adequate for going cleanly through a standard hydrogen target. In some cases, we may want to restrict target size, and the beam diameter may have to be only a few mm. Examples are cases where slow recoils have to come out or where hyperons have to be detected. In a very few cases, it may be desired to use the beam spot size to define a vertex in the plane perpendicular to the beam. This might require 1 mm. Let us choose a 1-cm diameter beam as "typical" with normal variations of  $\pm$  a factor of 3.

### Angular Divergence or Spread in Transverse Momentum

In an experiment an unobserved particle will carry off some transverse momentum. In a very general sense, the typical amount is in the region of 300 MeV/c. Therefore, for most experiments, particularly those using high beam flux, not able to measure the incident particle, a spread in  $p_{\perp}$  significantly less than 300 MeV/c will be required. A lower limit to the useful definition of  $p_{\perp}$  is around 3 MeV/c, the amount introduced by multiple coulomb scattering in a 6-in. liquid hydrogen target. Take 30 MeV/c as "typical" for the spread in  $p_{\perp}$  in a beam, and allow for variations of a factor of  $\pm 3$  as before.

### Implications of 2

Notice that 30 MeV/c and 1-cm diameter defines the same phase space as 300 MeV/c and 1-mm diameter, i. e., our "typical" beams are consistent with capturing a high proportion of the particles produced.

Notice also that a field integral of  $Bl$  kG-meters produces a change of  $30 Bl$  MeV/c in the transverse momentum of any particle. Therefore, lenses with  $\sim 10n$  kG-meters at the pole tips, where  $n$  is  $\lesssim 10$ , will be adequate for high-flux beams where particles with  $p_{\perp}$  of 300 MeV/c will have to be bent through  $\sim n$  times their production angle. For beams which use a restricted solid angle,  $n$  can be less. For flexibility in use, it would perhaps be sensible to use lenses in which the  $\int Bdl$  at the edge of the good-field region is  $\sim 20$  kG-meters as building blocks. In view of the fact that close to the experiment the spread in transverse momenta contained in the beam is likely to  $\sim 30$  MeV/c, quadrupoles with as little as 10 kG-meters at the pole tips are likely to be quite useful.

The useful quadrupole bore is determined by beam length, by manufacturing problems and by other considerations associated with such things as pole-tip scattering and the like. For example, it is difficult to imagine making a pole-tip veto to go inside a 1-in. bore lens. In discussing constraints of this last type, one is inevitably drawn towards current practice by, among other things, lack of imagination. Note that the use of intense beams without defining counter telescopes will lead people to want to use only a fraction of the available bore in the last lenses.

#### Other Factors Influencing Transverse Phase Space

Certain specific items of equipment, viz. DISC or threshold counters impose constraints.

DISC design (ECFA Vol. I, p. 357) aims at an angular resolution of 0.1 mrad. This is 15 MeV/c in  $p_{\perp}$  at 150 GeV/c. A useful diameter of 4 in. is envisaged. Fifteen MeV/c and 100-mm diameter is a factor of 5 more than the 30 MeV/c and 10-mm diameter envisaged for the phase space of our typical beam. Therefore, the DISC can be included and will be useable in a high-intensity beam.

Threshold  $\check{C}$  counter design has been considered in the LRL Studies. Lengths of  $\sim 30$  m imply angles of considerably less than 3 mrad.  $\pi$  or  $K \check{C}$  angles for proton threshold are  $\sim$  a few mrad. It does not seem likely that threshold counters will impose any additional constraints other than the existence of a straight beam path (which may go through quadrupoles) of about 30 m per counter.

Constraints are also imposed by the momentum resolution desired and by the angles of bend required to clear shielding. Note here that if large angles of bend are used, field lenses will become imperative for any but the smallest momentum bite.

### Momentum Bite and Resolution

There will clearly be a need for beams with  $\Delta p < M_{\pi}$ , i. e.  $\Delta p/p < 0.1\%$ . For a beam with a 300 MeV/c-mm horizontal phase volume, we can make the spread in  $p_{\perp} \sim 3$  MeV/c by going to a 10-cm wide beam. We then need  $BL \geq 100$  kilogauss-meters to get the desired 0.1% resolution. At 150 GeV, this is only a bend of 20 mrad. Much stronger constraints in bend angles needed are likely to come from the geometry of

the muon shield downstream of the production target and the desired spacing of experiments in the experimental area.

### Miscellaneous Unoriginal Notes

1. Small pitching magnets will be essential to compensate for misalignment of quadrupoles and the earth's field in long beams. Lach suggests putting windings in each lens for this purpose. The  $\int B dl$  needed is  $\int B dl$  at quadrupole poles  $\times$  misalignment tolerance/quadrupole bore. Doing this also means we shall need a good method to decide what currents to set. This might be done by collimators of the type used by Neale in the high-energy separated K beam at CERN or by using small counters which can be put in place remotely on the axis at each quadrupole (or quadrupole pair).

2. The cost of installing new beams at NAL will be very high. Therefore, each beam will have to serve several consecutive experiments, each of which may have different beam spot-angular divergence requirements.

Several suggestions have been made of ways in which this might be done. Maschke suggests to build in redundant quadrupoles in each beam, to allow the optics to be changed. The author suggests using triplets instead of doublets, particularly at the end of a beam. CERN has built beams with switch magnets towards the end which allow two side-by-side experiments to be run at different times.